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Artificial Neural Network Based Fault Detection and Fault Location in the DC Microgrid

Qingqing Yang[a], Jianwei Li[a]*, Simon Le Blond[a], Cheng Wang[a]

[a]University of Bath, Claverton Down, Bath, BA2 7AY, United Kingdom

Abstract

In DC microgrid, power electronic devices may suffer from over current during short circuit faults. Since DC bus systems cannot sustain high fault currents, suitable protection strategy in DC lines is indispensable. This paper presents a novel use of artificial neural network (ANN) for fault detection and fault location in a low voltage DC bus microgrid system. In the proposed scheme, the faults on DC bus can be fast detected and then isolated without de-energizing the entire system, hence achieving a more reliable DC microgrid. The neural network is trained based on the different short circuit faults in DC bus to ensure its validity. A microgrid with ring DC bus, which is segmented into overlapping nodes and linked with circuit breakers, is built in PSCAD/EMTDC to test the performance of the protection scheme.

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Keywords: Artificial neural network; DC microgrid; fault detection; fault location, short circuit fault

1. Introduction

Nowadays, a large amount of renewable powers and energy storage systems are introduced to the conventional power system [1]. However, the large penetration of distributed generations may challenge to conventional power generation and distribution system, such as the voltage rise, frequency fluctuations, and protection problems [2]. Therefore, the microgrid which is defined as a low voltage system with generations and energy storage systems providing electricity to local demand is becoming more and more attractive [3]. Many previous works have investigated the application of AC microgrid. However, DC microgrid has been proved to have many advantages over AC microgrid [2]. Firstly, DC power devices

* Corresponding author. Tel.: +44 7449015799.

E-mail address: jl977@bath.ac.uk (Jianwei Li), qy256@bath.ac.uk (Qingqing Yang).

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such as batteries and solar panels are largely integrated into the AC microgrid, which means a great many of converters are needed, resulting in large investment on power conversion system. In addition, the micro AC power supplies which have varying voltage or frequency from those of the utility grids also need power conversion [4]. Compared with AC system, the requirements of power converters are reduced in DC microgrid resulting in higher efficiency and lower investment [5]. Secondly, there is no requirement for synchronization, and the loss of the reactive power and harmonics in DC microgrid [1]. In addition, the DC microgrid system is more conducive to simpler and more efficient power electronic interface [6, 7]. Hence, building DC transmission network in microgrid, connecting the distributed power supplies and loads, has become a new research direction.

Even though DC microgrid has lots of advantages, there are still some challenges in DC microgrid protection [8, 9]. Generally, it is difficult to locate the fault before isolation and to extract useful information for fault location [10]. This paper focuses on DC bus fault detection and fault location. The rapid detection and location of fault, based on transient voltage signal or fault current signal, is very important in protection scheme. As indicates in [11-13], the ANN based method is one of the most efficient method for fault detection and fault location on AC grid and HVDC system because of its accuracy, robustness and fastness. However, to the authors' best knowledge, there is no published work for ANN applied in DC microgrid protection. Hence, this paper introduces the Artificial Intelligence (AI) based method for fault detection and fault location in a DC microgrid system. A DC microgrid is built in PSCAD/EMTDC to simulate the DC system under normal and transient conditions to analyze the fault profile and build training set for ANN. Different fault types with various fault resistances and fault locations are studied in the test network. Two neural networks are established for fault detection and fault location respectively. The faulted segment will be isolated, and the rest system will keep working. The simulation results show an accuracy performance of the proposed method.

2. System description and modeling

The structure of typical DC microgrid is shown in Figure 1, which mainly consists of wind power generation, energy storage system, loads and AC main grid connection four parts. The wind turbine is used as a typical distributed generation connected to the grid. The wind turbines working as a typical distributed generation are developed based on a simplified model in [14]. The converter station is operated under maximum power point tracking (MPPT) mode to capture wind energy as much as possible [15]. The DC battery energy storage with the bidirectional DC/DC converter is simulated as a storage unit based on [16] and worked as energy storage unit in this paper. During normal operation, battery works in the charging statues or as a back-up power supply. However, during island operation, battery energy storage is used as a slack bus to keep DC voltage stable and steady operation. DC loads directly connect to DC microgrid through DC/DC converter, and AC loads connect to grid by using VSC converter. When power supply is insufficient, load shedding control strategy will be applied to keep power balancing. DC microgrid is incorporated into the main AC grid by VSC converter with bi-directional power flow [17]. When the DC microgrid network is in normal operation, the active power balancing is kept by control DC voltage through VSC converter. But during the AC voltage drop cause by short circuit fault, VSC will lose the stability of controlling DC voltage, but limit the current.

Several kinds of topology such as ring type, radial type, and central-ring type and general topology can be used in DC system. Ring topology of DC microgrid is selected in this paper. Even though the investment will be increased using this topology due to the increase of DC transmission line length and capacity, which results in the increasing quantity of circuit breaker, this kind of topology is more flexible and robust. During a DC line fault, the circuit breakers operate and cut the fault at both ends of the line to keep stable operation with no power losses. Other part of the DC line will undertake the increase of transmission capacity. Hence, the ring topology can play the advantages of DC microgrid for an ideal networking.

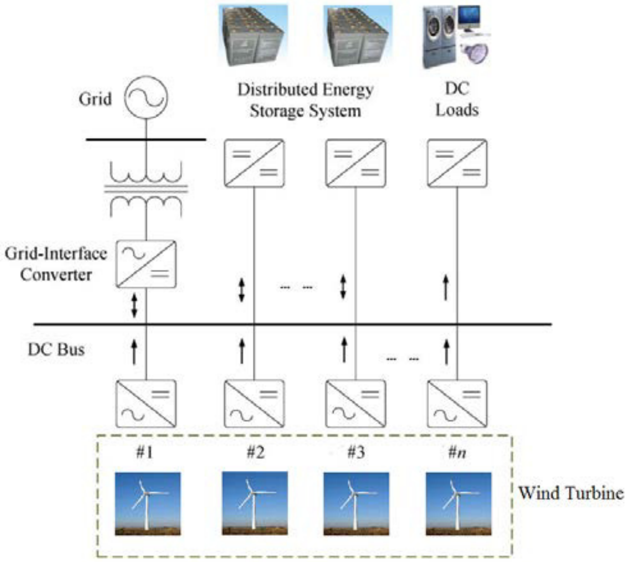

Fig. 1. The configuration of DC microgrid

3. ANN based fault detection and fault location methodology

Two types of faults are considered in the fault detection method in DC system, which are pole-to-pole fault and pole-to-ground fault [8]. In general, pole-to-pole fault is caused by external mechanical stress which can be regarded as permanent fault. Pole-to-ground fault happens with high probability which is a kind of temporary fault due to a branch drop or lightning. The appropriate line protection strategy is conducive to reduce the loss of the system and avoid the damage to the whole DC system. The protection strategies and post fault recovery capability of the system must be considered.

Compared with high voltage direct current (HVDC) system, low voltage DC system (LVDC) for power system is a relatively new concept [10]. During faults, a complete route will be developed through anti-parallel diode in VSC, so that converter station will release active power to the fault point. This may cause over current on DC bus and transmission line with a very high value and the change of current direction.

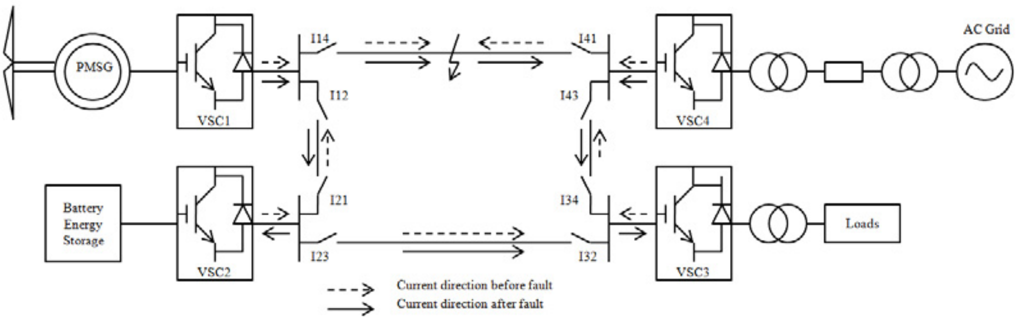

Fig. 2. Direction of currents under short circuit fault

The basic structure of the simulated system is shown in figure 2. DC circuit breakers which play a considerable role in DC fault isolation are installed at both end of the line to break the fault within milliseconds. The direction of current before and after fault can be clearly seen. On different faulted segment, the directions of current are varying.

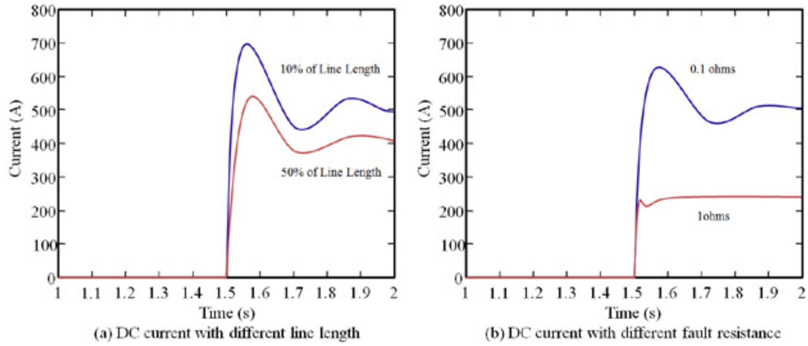

Fig. 3. DC current under short circuit fault

The current signal gives the appropriate information regarding the different power system condition (figure 3). During a fault, currents on every terminal will increase rapidly to a very large value which may result in severe damage to the electronic devices. It can be also obtained that the magnitude of fault current changes under different fault locations and different fault resistances. The slopes of the current increase and peak magnitude are difference as well as can be seen in figure 3 (a). It can be concluded that the same fault location appears the same rate of current rise. Hence, the current signals on both end of the line are used as inputs in the designed ANNs.

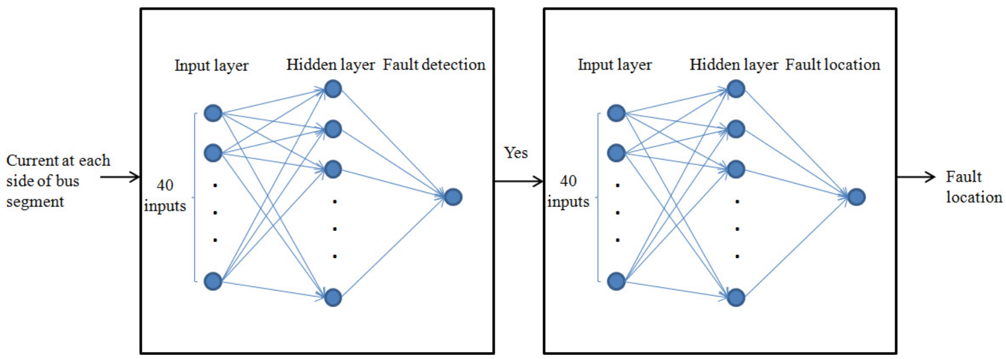

Fig. 4. Artificial neural network model

Figure 4 shows the developed ANN modules for the fault detection and fault location on the bus segments of the simulated system. The artificial intelligence algorithm will help the system make a correct decision to tell whether there is a fault and where the fault occurs. As indicated in the DC fault analysis, samples of the current waveforms obtained are selected for ANN training under different conditions to detect faults and locate the faults. ANNs will consider the direction, slope of current increase and the information obtained from DC current signals. Two ANNs are designed in the protection scheme. One ANN is to detect the fault and the other one is to determine the fault location on the dc bus segments with the same input data. After the detection of fault, circuit breakers are used to isolate the bus segment after faults.

4. Simulation test

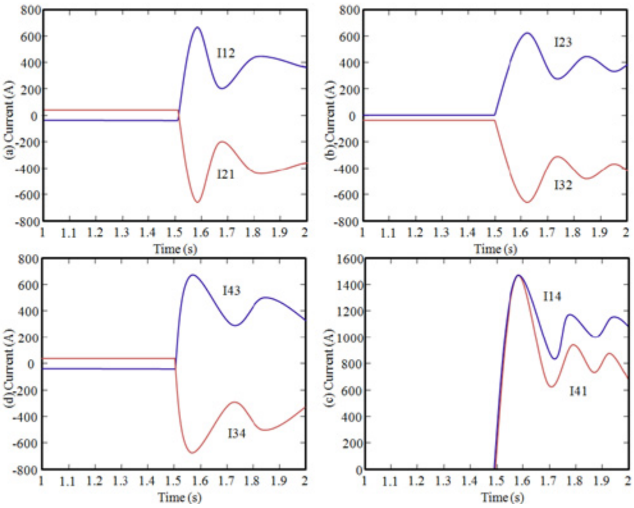

Fig. 5. DC current of transmission line

Simulation is completed based on the DC microgrid model introduced above using PSCAD/EMTDC as a platform. The power in network for wind turbine, battery energy storage, loads and AC grid are 22 kW, 10kW, 30 kW and 18kW respectively. The fault is set at 1.5 s last 0.01s on the DC bus segment between wind turbine and AC grid. The current data detected from each terminal of the bus segments are shown in figure 5. The surge of current and the change of positive/negative value obviously displayed.

The DC currents on both end of the line are selected as input data. Multilayer feed-forward ANN is used in this paper. Fault detection and fault location processes are completed in two ANNs. With the same input vectors applied in two different ANNs, the fault can be accurately detected and the location of fault on bus segment can be measured.

Table 1. The results based on ANN method

Fault type	Fault resistance	Fault location	Measured location	Error
Pole-to-pole	0.7	56%	55.32%	0.68%
Pole-to-ground	0.65	78%	78.09%	0.09%
Pole-to-pole	2.5	25%	25.25%	0.25%
Pole-to-ground	6	47%	46.84%	0.16%
Pole-to-pole	1.2	89%	88.82%	0.18%
Pole-to-ground	0.25	11%	11.03%	0.03%

A sampling rate of 5 kHz is used to acquire signals and current data windows of 20 samples are obtained at each side of the source, which are applied as ANN input. Therefore, the designed ANN receives 40 input vectors to the neural network in figure 4. Different cases are considered for neural network training including the situation in different fault resistances and fault locations. 20 samples of cases with fault resistance of 0.1 Ω, 0.5 Ω, 1 Ω, 2 Ω, 10 Ω and fault location of 10%, 30% 50%, 70%, 90% in each bus segments are detected for data training. Fault detector and locator are trained with its corresponding 2250 cases. Results are presented in table 1. In the result, the faults can be detected correctly on each bus segments through the designed ANN with 100% accuracy. With the accurate detection, the fault on each segment will be isolated by circuit breakers at the terminals very fast. In addition, the error for fault location is detected within 1%.

5. Conclusions

An artificial neural network based fault detection and fault location method has been presented in this paper. The detailed modeling of DC microgrid including wind turbine, battery energy storage system, loads and AC grid is simulated in PSCAD/EMTDC. Through analyzing faults of the modeled system, DC current signals are used as inputs in the presented method. The results demonstrated that any types of DC faults can be accurately and fast detected. In addition, the fault location can be detected within 1% error. The ANN based method can be regarded as a very efficient method for DC microgrid.

6. Copyright

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